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ANALYSIS

Cost-effectiveness analysis of woodland ecosystem restoration

Douglas C. Macmillan [a,*], David Harley [b], Ruth Morrison [c]

[a] *Department of Agriculture, MacRobert Building, 581 King St, University of Aberdeen, Aberdeen AB24 5UA, Scotland, UK*
[b] *Royal Society for the Protection of Birds, Sandy, Bedfordshire, UK*
[c] *Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen AB15 8QH, Scotland, UK*

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Abstract

Ecosystem restoration has emerged as an important approach to safe-guarding biodiversity. In Scotland, the government is committed to restoring the natural woodland ecosystem of mountain areas and gives payments to landowners for establishing new woodlands. Although the aim of the policy is to restore a natural woodland ecosystem, the rate of payment available is correlated with the costs of establishment rather than the contribution new woodlands make to restoring the natural ecosystem. In this study, the cost-effectiveness of government expenditure is investigated by comparing the cost of grant aid with the ecosystem restoration potential of new woodlands. An expert-based system for scoring ecosystem restoration potential is described and applied to over 200 new woodlands in a Geographic Information System. New woodlands varied considerably with respect to both cost and ecosystem restoration score, with the most cost-effective woodlands established close to existing woodlands using natural colonisation techniques. Overall ecosystem score was negatively correlated with government expenditure. Alternative approaches to improving the cost-effectiveness of grant aid are discussed.

Keywords: Cost-effectiveness analysis; Ecosystem restoration; Biodiversity; GIS

1. Introduction

Globally the rate of species extinction is accelerating. Pollution, persecution, exploitation, and perhaps most importantly, ecosystem fragmenta-

* Corresponding author. Tel.: +44 122 4274128; fax: +44 122 4273731; e-mail: d.macmillan@abdn.ac.uk

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tion have all led to erosion of the world's genetic pool (Spellerberg, 1995). However, following the 1992 'Earth Summit' in Rio, renewed emphasis has been placed on the rehabilitation and restoration of degraded ecosystems to safe-guard biodiversity (Article 8f, Convention on Biological Diversity). In Europe, for example, member states of the European Union (EU) are obliged to protect rare species and restore habitats under the Habitats Directive (92/43/EEC), and environmental enhancement is central to the reform of the Common Agricultural Policy (CAP).

Implementation of biodiversity initiatives will necessarily involve considerable expenditure. In the UK, 14 Habitat Action Plans for conserving biodiversity are expected to require additional public funding of about £40 million (48 million ECU) by 2010 (Biodiversity Steering Group, 1995). Evaluating the benefits in economic terms is, however, extremely difficult and thus poses a problem for policy makers anxious to portray expenditure as 'value for money'.

Economic appraisal of policies with environmental output through cost-benefit analysis (CBA) is difficult because the benefits, such as species protection and maintenance of genetic resources, are non-market goods. Although methods for estimating these benefits, such as contingent valuation (CV) are being developed, their suitability for complex biodiversity issues is not yet proven (Hanley and Spash, 1993; Diamond and Hausman, 1994), and they are contentious with environmental interest groups (Bowers, 1992). Cost-effectiveness analysis (CEA), which does not rely on monetary valuation, but selects projects on the basis of cost and effectiveness in relation to a pre-determined objective (Gittinger, 1982), may offer considerable potential as an appraisal method.

This paper describes the development and application of an expert scoring system to evaluate the cost-effectiveness of government expenditure on a programme to restore the Caledonian woodlands of Scotland. Caledonian woodlands represent an important western extension of the European boreal forest and support many rare species including the Scottish crossbill (*Loxia scotica*), Britain's only endemic bird species, and capercaillie (*Tetrao urogallus*). As a result of exploitation for timber, agricultural clearance, and over-grazing by sheep and deer, these woodlands now occupy less than 5% of their range in pre-historic times (Fig. 1) and restoration of the Caledonian forest is an important objective of the UK's Biodiversity Action Plan (H.M. Government, 1994).

2. Restoration of the Caledonian woodland ecosystem

The Government has established an expansion target for Caledonian woodlands of 25000 hectares by 2005 (H.M. Government, 1994). In order to meet this target financial incentives are available under the Woodland Grant Scheme (WGS) to all landowners within the natural range of the original Caledonian forest. The objective of this grant aid is to 'create new woodlands which emulate the shapes, distribution and ultimately the structure of a natural woodland system' (Forestry Commission, 1994b).[1]

Participation in the WGS is voluntary and the rate of grant varies according to the cost of restoration. For example, the highest rate of grant per hectare is available for planted woodlands less than 10 ha in area, whereas woodlands estab-

Table 1
Grant rates available for new Caledonian woodlands under the WGS[a]

Options	Rate per hectare (£ ha^{-1})
New planting	
Less than 10 ha	£1350
10 ha or more	£1050
Natural colonisation	£525 plus 50% of agreed cost for work to encourage colonisation

[a] Source: Forestry Commission (1994b) The Woodland Grant Scheme Applicant's Pack. HMSO, London.

[1] Secondary aims include the enhancement of aesthetic value, the provision of recreational opportunities and the production of utilisable timber.

Fig. 1. Current and former distribution of natural boreal woodland in Scotland.

lished through natural colonisation attract a much lower level of grant (Table 1). Although all new woodlands must meet a number of conditions relating to environmental protection (e.g. management of water courses) and the genetic provenance of planting stock (Forestry Commission, 1994a), landowners have considerable flexibility to choose the location and extent of new woodlands and methods of establishment.

The principle of awarding grants as compensation for expenditure and/or profit foregone incurred by landowners as a consequence of participation in a conservation programme is widely applied in UK land use policy. Although necessarily suited to cases where land management or use is constrained by mandatory conservation designations it would appear to be less appropriate for voluntary schemes, where the government is attempting to purchase environmental benefits, rather than compensation for diminished property rights (Hodge, 1995).

In the case of the WGS for Caledonian woodlands, the compensation principle raises two fundamental concerns. Firstly, the private benefits of woodland creation are not taken into account when setting grant rates for different restoration options. As new planting has the potential to produce greatest timber revenue landowners have an extra incentive to create woodlands using this approach rather than through natural colonisation. During the first 5 years of the scheme Gill et al. (1995) reports that over 80% of all new Caledonian woodlands were established by planting. Secondly, although grants are intended to purchase environmental benefits arising from the restoration of the Caledonian woodland ecosystem, woodlands which have been criticised because of their low ecosystem value currently attract the highest rate of grant (RSPB, 1993). Consequently value for money, in terms of ecosystem benefits per pound (£) of government expenditure for these woodlands is very low.

Although UK forestry policy includes a commitment 'to promote research into the measurement and cost-effective enhancement of biodiversity' (para 3.34, H.M. Government, 1994), there has been no attempt to investigate the effectiveness of public expenditure in relation to Caledonian woodlands. This is mainly due to the difficulties of accurately assessing the extent to which new woodlands contribute to the programme's objective of restoring a natural ecosystem. In the next section we describe one approach, which incorporates an expert-based system for scoring ecosystem restoration potential, to evaluate the cost-effectiveness of grant-aid.

3. Cost-effectiveness analysis of woodland restoration

In general, CEA has obvious application where policy is 'constrained by existing environmental targets or objectives', such as 'previous political choices, domestic legislation, EC directives or international agreements' (DoE, 1991). In some applications of CEA, the objective can be simply defined in terms of a scientific standard (e.g. tonnes of SO_2) which is reasonably easy to measure. In this case CEA chooses the least cost option for meeting the objective and there is no need for a separate measure of effectiveness (either an option meets the objective or it does not). However, in the case of woodland ecosystem restoration, the assessment of effectiveness is more complicated because the objective is not so easily interpreted and the extent to which individual woodlands meet the objective varies considerably.

A natural woodland ecosystem performs a range of important functions including habitat provision, nutrient cycling, soil protection and the regulation of climate and the hydrological cycle. New woodlands will differ with respect to the effectiveness in emulating these functions. For example, internal features such as tree species and structural diversity influence woodland processes (e.g. nutrient cycling) and habitat suitability, while locational attributes (i.e. position in the landscape) can affect gene flow and the survival of meta-populations of specialist woodland species (Spellerberg and Gaywood, 1993; Hanski and Thomas, 1994).

3.1. Measuring ecosystem restoration potential

In the absence of reliable quantitative models which link woodland attributes to ecosystem restoration potential, ten leading experts in woodland ecology were invited to develop an evaluation system. In order to obtain a wide interpretation regarding the programme objective, the panel was drawn from a variety of organisations including research institutes, environmental groups, and state agencies, such as the Forestry Authority and Scottish Natural Heritage.

Initially each expert was individually asked to perform three tasks: (i) to select attributes, (ii) to weight attributes, and (iii) to develop a scoring system to transform the physical attribute value to a scale between one and ten which reflected her/his value function. Following this phase the experts were then brought together at a workshop to give them the opportunity to agree on attributes and to adjust their scoring system following a group discussion.

3.1.1. Attribute selection

Experts were asked to take a holistic view of ecosystem restoration when considering attributes rather than focus on certain species of plants or animals. The primary constraint on attribute selection was data availability. There were two data sources for new woodlands: (i) maps and supporting information from the Forestry Commission on silvicultural methods for all new Caledonian woodlands[2] approved for grant aid under the WGS and (ii) MLURI's land cover database (MLURI, 1993).[3] Both sets of data were stored in a Geographic Information System (GIS) to facilitate subsequent analysis. Appendix A lists the data available for the evaluation.

Eleven attributes were agreed upon by the expert panel. Five describe internal features of the woodland, while the remainder relate to concepts drawn from landscape ecology. These are described briefly below:

3.1.1.1. Internal features. (1) Genetic integrity: Since the last ice age Caledonian woodlands have evolved in relative isolation from the continental boreal forest and have developed a distinctive gene pool. An important restriction under the conditions of the grant is that only genetic resources derived from Caledonian stock can be used.[4]

(2) Species composition: Species composition influences food supply and nesting sites within woodland (Fuller et al., 1995), and would vary naturally depending on seed source and local site suitability (Rodwell and Patterson, 1994). Colonisation, being a natural method of colonisation would reflect these factors, whereas new planting requires a 'natural' mix of species through careful planting design (Forestry Commission, 1994a).

(3) Tree density and patchiness: Variable tree densities and patches of open habitat are distinctive features of natural woodlands, providing feeding locations and cover for woodland species. Planted woodlands are required to mimic the distribution of trees found that would result from natural colonisation (Forestry Commission, 1994a).

(4) Precursor vegetation: New woodlands can be established on a range of semi-natural habitats. Ground flora at establishment influences the extent to which a characteristic woodland flora will develop through time. Experts were also asked to consider the extent to which ground cultivation will affect precursor vegetation. For example, ploughing to improve drainage and soil fertility can severely disrupt existing ground flora and trigger an explosion of aggressive weed species such as *Deschampsia cespitosa* (Rodwell and Patterson, 1995).

(5) Method of deer control: Low intensity grazing is a feature of natural woodlands and helps to maintain diversity of composition and structure. High numbers of deer damage trees and ground flora (Gill et al., 1995), and in the absence of natural predators, such as the wolf, grazing has to be controlled by exclusion (fencing) or by shoot-

[2] Approximately 200 woodlands in total.

[3] The Land Cover database is a national census of land cover in Scotland and identifies more than 100 habitat types.

[4] Scots pine derived from central European stands have been widely planted within the area of the original Caledonian forest.

ing. The method used to control deer will influence the composition and structure of the habitat (tree colonisation, ground flora, etc.), with shooting most likely to emulate the effects of low grazing expected under natural conditions.

3.1.1.2. Locational attributes. (6) Area of new woodland: The Caledonian forest was once an extensive ecosystem covering many thousands of hectares, and certain specialist species (e.g. red squirrels) require relatively large contiguous areas of woodland.

(7) Area of surrounding natural woodlands: A new woodland located in a region containing a significant proportion of mature natural woodlands is more likely to be colonised by specialist species. These new woodlands are also likely to provide important additional habitat for existing populations of woodland species.

(8) Distance to surrounding woodlands: The closer existing woodlands are to a new woodland the greater the possibility of colonisation by woodland specialists, and for the restoration of ecosystem processes and energy flows. Fuller et al. (1995) and Opdam et al. (1984), for example, found that species of specialist woodland avifauna occur less frequently in isolated woods.

(9) Number of surrounding woodlands: Several studies have shown that, due to differences in composition, structure and management, the combined species total from several small patches may be more than the total present on one patch of equivalent area (Kirby, 1995). This attribute is therefore slightly different to attribute 7 since it takes account of the possibility that colonisation opportunities are likely to be higher if there are a large number of woodlands in the vicinity of the new woodland.

(10) Area of associated habitat surrounding new woodland: The extent to which a new woodland will be colonised by specialist woodland species and can contribute to the support of their meta-populations will also be influenced by the matrix of non-woodland habitats in the surrounding area. Habitats such as bogs and sedge-rich flushes are associated with a woodland ecosystem and other vegetation communities like heather moorland, which may have only recently lost their woodland cover, will also provide habitat for specialist woodland species. On the other hand some habitats, such as arable land, can represent a barrier to species (Peterkin and Game, 1984). Each expert was asked to define the range of associated habitats from the Land Cover Classification.

(11) Adjacent habitat: This attribute is related to attribute 10, but highlights the importance of interactions between the boundary of a new woodland and the adjacent habitat (Spellerberg, 1995).

Table 2
Overall ranking of attributes based on expert weighting

Attribute	Overall ranking	
	10 Years	100 Years
1. Genetic integrity	5	8
2. Species composition	1	2
3. Tree distribution	3	10
4. Precursor vegetation	4	11
5. Method of deer control	2	3
6. Area of new woodland	6	1
7. % Woodland in 5-km radius	11	5
8. Number of woodlands in 5-km radius	9	6
9. Average distance to woodlands in 5-km radius	10	9
10. % Associated habitat in 5-km radius	8	6
11. % Boundary with associated habitat	7	4

3.1.2. Weights

In order to quantify the relative importance of attributes to the overall assessment of ecosystem restoration potential, experts were asked to weight each attribute on a scale from 0 (little or no importance) to 10 (very important). Opportunity was also given to adjust the weights through time in order to reflect changes in attribute significance as new woodlands mature. Two time periods were selected: Year 10 and Year 100.

Each expert provided his/her own weighting system. The overall ranking for the eleven attributes, from the weighted average of the experts is shown in Table 2. Attributes relevant to inter-

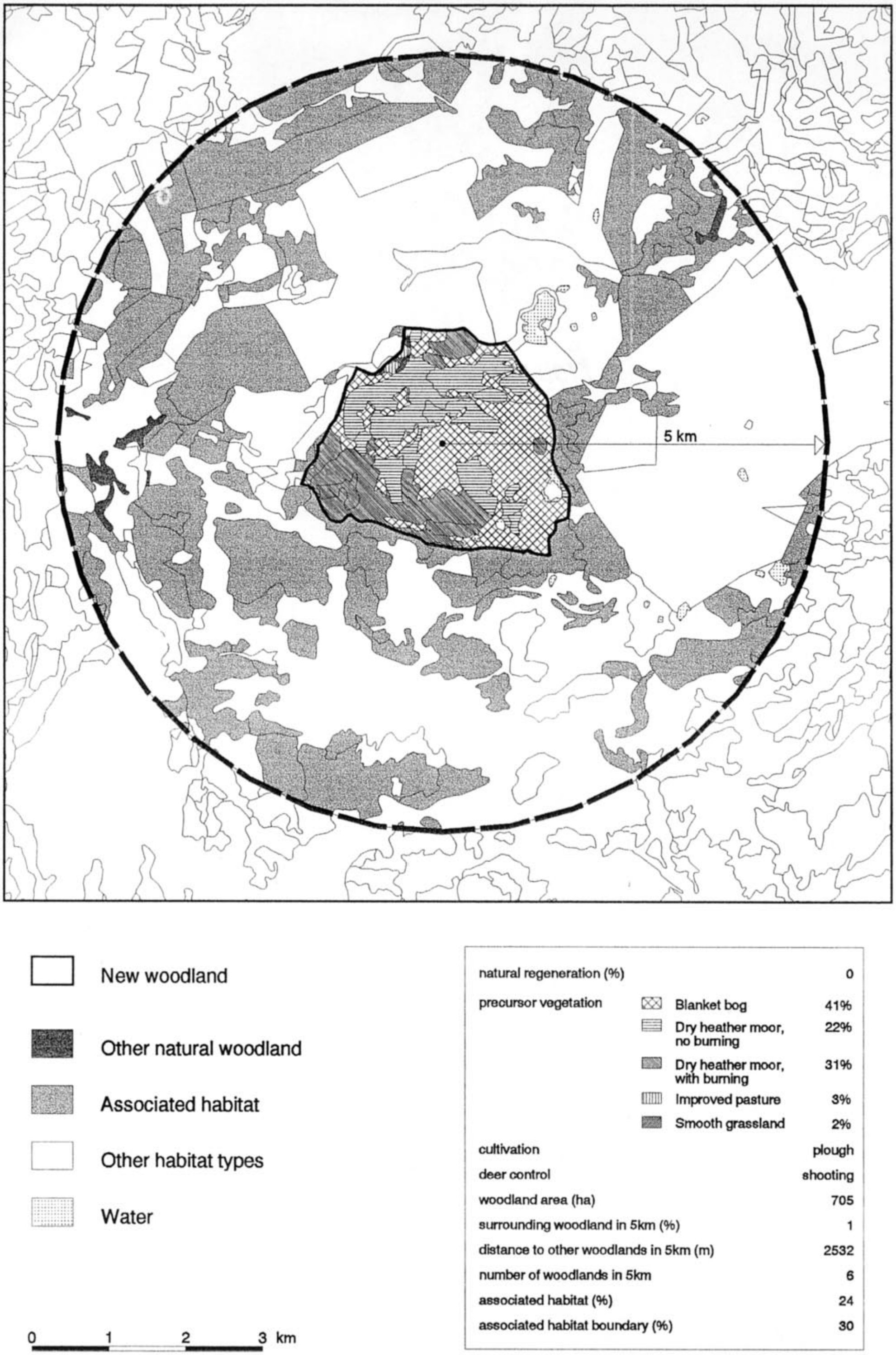

Fig. 2. Attributes of a new natural woodland: an example.

nal features of woodlands, such as species composition and distribution, are more important at year 10 than year 100. This is because structural change, succession and disturbance would slowly mask any initial differences between new planting and natural colonisation in these attributes. The weight attached to precursor ground vegetation also decreased because new woodlands were expected to develop a more natural ground flora through time.

In year 100, the area of the new woodland emerges as the most important attribute. Other attributes associated with colonisation potential were also more influential (attributes 7–11). This reflects the time-dependant nature of the colonisation process, with immature new woodlands unlikely to be colonised by a range of species regardless of their location or method of establishment.

3.1.3. Attribute scoring system

The final component of the evaluation was the scoring system for each attribute. Each expert was asked to develop a scoring system to transform the physical value of the attribute (e.g. percentage natural regeneration) to an index which reflected his/her value function within the range 0 (no contribution to the objective) to 10 (maximum possible contribution).

Since no data were available to measure directly genetic integrity, species composition, and tree distribution, it was necessary to base scoring for these attributes on the percentage of new woodland created through natural colonisation. Experts were therefore requested to provide a scoring system for these attributes which reflected the extent to which they considered that colonisation was more effective than new planting. For attributes 5 (deer control) and 6 (area) the relevant information was available from the grant application form, while for attributes 7–11 the data were calculated in the GIS from the land cover data set based on a 5-km radius around the new woodland (Fig. 2).

The pattern of scoring was fairly consistent across all ten experts for most locational attributes. For example, all experts indicated that effectiveness increased with area of the new woodland (Fig. 3a). The pattern of scoring was also consistent across experts for attributes 2 (species composition) and 3 (tree distribution), with wood-

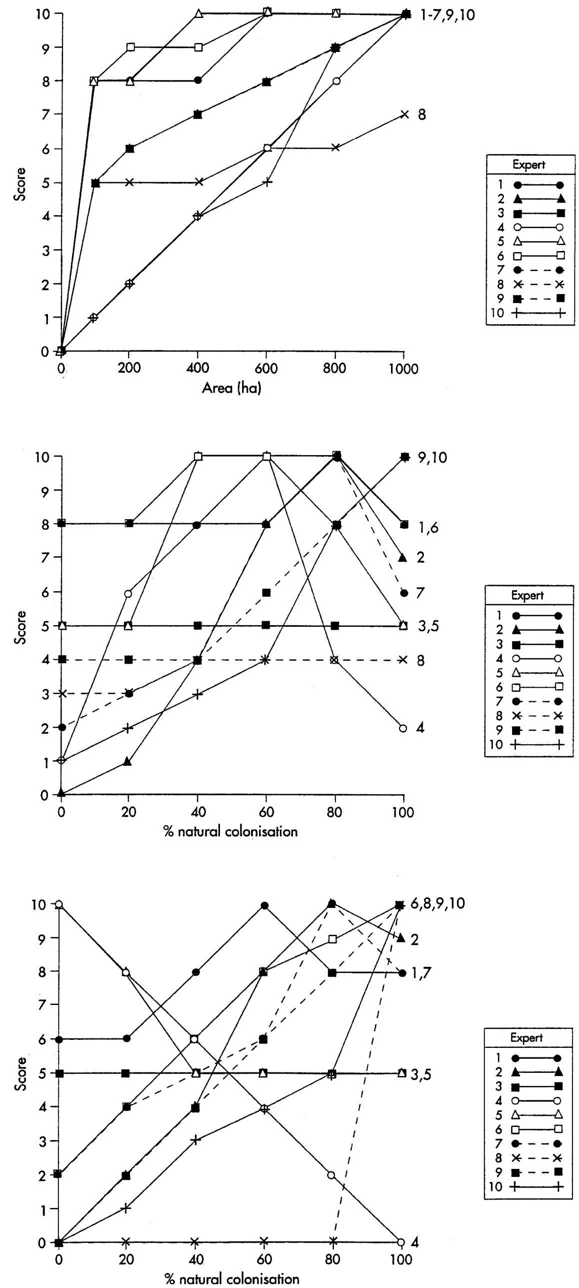

Fig. 3. Value functions of individual experts for selected attributes. (a) Attribute 6 (area of new woodland), (b) attribute 2 (species composition), (c) attribute 1 (genetic integrity).

Table 3
Estimates of coefficients for the regression between woodland ecosystem score and woodland attributes

Variable	*B*	se *B*	*T*-value	Sig *T*
Constant	0.7684	0.1075	7.15	0.000
% Area of woodland in 5-km radius	0.0186	0.0030	6.17	0.000
% Area associated habitat in 5-km radius	0.0046	0.0011	4.02	0.000
% Woodland boundary associated habitat	0.0026	0.0008	3.46	0.001
Intensity of cultivation (low = 1; high = 0)	0.1164	0.0398	−2.92	0.004
Method of deer control (shoot = 1; fence = 0)	0.4213	0.0445	9.46	0.000
Distance to other woodlands in 5-km radius	−0.0002	0.0000	−7.50	0.000
% Heather in precursor vegetation	0.0059	0.0005	12.75	0.000
Area of the scheme (ha)	0.0017	0.0002	11.21	0.000
% Natural colonisation	0.0127	0.0004	29.42	0.000

lands with 60–80% of their area colonised naturally scoring highest (Fig. 3b). These woodlands were preferred by the experts because they considered that a small proportion of intervention through new planting would provide an opportunity for enhancing these characteristics. Only for attribute 1 (genetic integrity) was there any degree of inconsistency between experts' scores with some experts favouring colonisation and others new planting (Fig. 3c). This reflected diverging views about the extent to which it was possible to prevent contamination of the seed bank by non-native pollen.

3.1.4. Overall ecosystem restoration score

The ecosystem restoration score for an individual new woodland under each attribute (A_i) was calculated by multiplying the score (S_i) achieved by the attribute weight (W_i). Summing across all attributes ($A_1 - A_{11}$) gave the overall measure of effectiveness (E_{jk}) for a new woodland (j) under each expert (k):

$$E_{jk} = \sum_{i=1}^{11} W_{ijk} * S_{ijk}$$

To standardise the overall score across experts the woodland score was weighted by the overall mean score and standard deviation of each expert.

$$E^*_{jk} = \frac{E_{jk} - \bar{E}_j}{\sqrt{\text{var } E_{jk}}}$$

In order to investigate statistically the influence of individual attributes on the overall score of individual pinewoods the standardised 100-year effectiveness score (E^*_{jk}), averaged across experts, was regressed against the woodland attributes. The estimates and standard errors for the attributes selected in a step-wise procedure are presented in Table 3. (The R^2 for the regression equation was 0.88 and the F value was significant at 0.1% level).

The woodland ecosystem score increased with area and proximity of surrounding woodland, the percentage of natural colonisation, area of new woodland, and the percentage of associated habitat surrounding the woodland. Woodland established using intensive cultivation methods (e.g. ploughing) and which utilised fencing rather than shooting for controlling deer had a lower ecosystem score.

3.2. Grant cost

Standard grant payments for each new woodland were calculated on a pro-rata basis depending on the percentage planted and colonised naturally (Table 1). Discretionary payments available to cover 50% of the cost of specific operations necessary to encourage natural colonisation, such as scarification and fencing, were estimated based on silvicultural information for each woodland available in the GIS dataset.

Table 4
Average grant cost and woodland ecosystem score at 10 and 100 years

Restoration options	Grant (£ ha^{-1})	10-Year score	100-Year score
New Planting[a]			
Less than 10 ha	£1350	−0.785	−0.796
10 ha or more	£1050	−0.166	−0.206
Natural colonisation[b]	£933	1.033	0.942

[a] All new woodlands with more than 80% planting.
[b] All new woodlands with more than 80% natural colonisation.

3.3. Cost and effectiveness

The cost effectiveness of each woodland was compared by correlating the grant cost with the standardised ecosystem restoration score. Grant cost and score were negatively correlated in both year 10 and year 100 ($r = -0.52$ and -0.56 respectively). In other words, woodlands which attracted more public funding were less effective in meeting the policy's objective of restoring a natural woodland ecosystem.

Table 4 presents the average grant cost and ecosystem score for the three basic grant options at 10 and 100 years. At both time periods, small planted woodlands (less than 10 ha) had the lowest score and were most expensive, while woodlands predominately established through natural colonisation were cheapest and had the highest score. From 10 to 100 years, the cost-effectiveness of woodlands established predominately through planting increased, while it decreased for natural colonisation. This is a result of the reduced overall weighting given by the experts to attributes evaluated on the basis of percentage natural colonisation.

Overall woodlands established using natural colonisation perform better than planting in terms of ecosystem restoration score for a number of reasons. Firstly, it is preferred to planting by most experts under the scoring systems for attributes 1–3. Secondly, natural colonisation performs well under attribute 4 because it involves less intensive cultivation than planting. Finally, since colonisation must take place in fairly close proximity to existing seed sources it scores highly under attributes which relate to the location of surrounding woodlands.

4. Discussion

This study has shown that grant payments for woodland restoration are poorly correlated to ecosystem restoration score as measured by an expert group of ecologists. This situation has arisen because grant rates are linked to establishment cost rather than the value of the ecological benefits generated by individual woodlands. Although the principle of paying compensation for costs incurred was introduced to deal with mandatory conservation constraints, as in the case of Sites of Special Scientific Interest, it would appear to be an expensive approach to purchasing environmental benefits from landowners when voluntary participation is involved.

Value for money from the WGS could be improved in several ways. One approach would be to increase the grant rate for natural colonisation and reduce it for new planting, in order to increase the supply of land for the former relative to the latter. Because the establishment costs associated with natural colonisation are relatively low, the rate of grant for natural colonisation required to stimulate greater participation among landowners is likely to be significantly less than the rate currently offered for new planting. Also, since planting can generate private benefits to the landowner from timber and sport, a reduced rate of grant may not lead to a substantial reduction in the supply of land under this option. Hence,it is likely that the government's biodiversity target of 25000 ha could be met at lower cost and generate substantially higher ecosystem benefits than under the present system. To ensure that the target is achieved, the actual level of grant available for colonisation and planting could be allowed to float upwards or downwards depending on the supply of eligible land for afforestation as a function of grant levels.

Other approaches which would also lead to an improvement in the cost-effectiveness of grant aid include more stringent environmental constraints or restricting grant aid to the most suitable sites. A disadvantage of the latter approach is that it would considerably reduce opportunities for woodland expansion and would prove unpopular with those landowners who subsequently found themselves excluded from the programme as a consequence. A bidding system would be more flexible and would allow the state to select applications on the basis of environmental performance and public expenditure. The Conservation Reserve Program in the USA uses a competitive bidding process which involves a scoring system for environmental performance. Value for money is enhanced because landowners, in order to improve the probability of selection, are encouraged to submit proposals for funding which are of high environmental value and which reflect their private opportunity costs (Heimlich and Osborn, 1993).

Typically CEA focuses on the evaluation of policies where there is a clearly stated objective. Where there are multiple objectives CEA becomes more complex and weightings have to be attached to the different outputs.[5] In the case of new Caledonian woodlands, for example, weights could be attached to secondary objectives such as the enhancement of landscape, the provision of recreational opportunities, and the production of timber. In this form of application CEA becomes more or less analogous to CBA, with the weights replacing prices (OECD, 1989). Where a wider range of outputs are being considered it may be desirable to include a wider range of 'stakeholders'. For example, it would be appropriate to ask members of the general public to help evaluate landscape and recreational benefits.

The expert-based approach described here is likely to be best suited to policies where there is considerable environmental complexity and which requires a high level of understanding about scientific and technical issues. Problems with information overload and bias associated with CV when it is applied to complex issues such as biodiversity are therefore considerably lessened. However, as in CV, there is the possibility that experts involved in a CEA exercise will engage in strategic behaviour to influence the outcome of the evaluation. Although the consensual approach involving round-the-table discussions described here is likely to reduce the risk of this happening, it is also important that the entire process is transparent and reproducible, and that all stakeholders are represented.

5. Conclusions

In this study an expert-based GIS system for scoring new woodlands on the basis of their ecosystem restoration potential showed that government expenditure on grant-aid was negatively correlated with the ecosystem benefits of new woodlands. This situation has arisen because the level of grant aid available for new woodlands is directly linked to the cost of establishment. Cost-effectiveness would be improved if decision-makers took greater account of the ecosystem restoration potential of new woodlands, for example by reducing payments for new planting and increasing them for natural colonisation, or by introducing stricter environmental standards. More generally, CEA which incorporates environmental expert judgement to produce a non-monetary measure of complex biodiversity benefits should prove to be an attractive appraisal method to both policy-makers and environmental groups.

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[5] If cost is included as a one of the criteria then this form of analysis is referred to as Multi-Criteria Analysis (Janssen, 1994).

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Appendix A. Attributes of new natural woodlands stored in the GIS

Attribute	Description
Area	Area grant aided with boundary (hectares)
Digitised boundary	Digitised from 1:10 000 maps
Soil type	Available from 1:250 000 scale soil maps
Elevation	Available from digital terrain model
Establishment operations	Recorded on grant application
Cultivation method	
Fertiliser	
Weeding	
Fencing	
% Natural colonisation	
Land cover data associated habitat	

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